THE LARGE-SCALE MAGNETIC FIELD

IN THE SOLAR WIND

by

L.F. Burlaga
and
N.F. Ness
Laboratory for Extraterrestrial Physics
Goddard Space Flight Center
Greenbelt, Maryland

ABSTRACT

The large-scale, three dimensional magnetic field in the interplanetary medium is expected to show the classical spiral pattern to zeroth order. However, systematic and random deviations can be expected, although their nature and magnitude cannot be predicted. The sector structure should be evident at high latitudes, but the actual extent is unknown and the shape of the sector boundaries is controversial. Interplanetary streams will probably determine the patterns of magnetic field intensity but the actual patterns cannot be calculated at present because of our limited knowledge of speed profiles and the source conditions. The large-scale spiral field can induce a meridional flow which might alter the field geometry somewhat. The non-uniformities caused by streams will probably significantly influence the motion of solar and galactic particles. Unambiguous and detailed knowledge of the 3-dimensional field and its dynamical effects can only be obtained by in situ measurements by a probe which goes over the sun's poles.

I. INTRODUCTION

One cannot be c. tain of what will be observed on an out-of-the-ecliptic mission. It is basically exploratory. One can try to predict what will be seen, using current theories and the available interplanetary observations, and this paper attempts to do so for the interplanetary magnetic field. However, extrapolations to as little as 10° above the ecliptic are highly uncertain. Only in situ measurements can provide us the unambiguous and detailed knowledge that we seek.

Many of the properties of the magnetic field observed in the ecliptic plane follow from a simple relation which is valid when the magnetic stresses are not so large as to appreciably alter the motion, viz.

$$\underline{B}(r) = [\rho(r)/\rho_o] \underline{B}_o \cdot \nabla_o \underline{X} \tag{1}$$

where $\underline{B}(r)$ is the field in a radially moving volume element with constant speed, ρ is the density, $\underline{B}_o$ and ρ_o are the field and density at some surface near the sun, and $\nabla_o \underline{X}$ is the gradient of the displacement vector which is determined if the speed is known on the source surface. Thus, if B_o, ρ_o and V_o are known at some inner boundary (say 0.1 or 0.2 AU), and if $\rho(r)$ is known, then to good approximation one can project or map the field anywhere within 1 AU by (1), if the magnetic stresses can be neglected. This approach to the interplanetary magnetic field is discussed in Schatten (1972), Nolte and Roelof (1973), and more generally in Burlaga and Barouch (1975) and Barouch and Burlaga (1975a). It is valid for both time-dependent flows and steady flows.

Very little is known about the latitudinal variations of V near the sun $(V_o(\theta))$ so one must be content to explore several reasonable alternatives in order to study the effects of $\nabla_o \underline{X}$ on the three dimensional field. Of

course, the simplest assumption is V=constant, which gives the spiral field, as discussed below.

The values of $B_0(r_0,\theta,t)$ can be estimated by projecting photospheric magnetic field measurements upward through the solar envelope to the Alfven point and beyond. Several techniques for doing this are available in the literature, although none is completely satisfactory. The problem is illustrated in Figure 1 from Schatten (1971), which shows a sketch of an eclipse in which the lines presumably represent magnetic field lines. One sees a variety of structures. Near the sun, the field is complex with many closed loops visible at low latitudes. Farther from the sun, the field lines generally tend to diverge and to become nearly radial. This is represented formally by assuming potential fields near the sun and supposing that only the lowest order harmonics contribute to the interplanetary field. The transition to radial fields is generally made artifically at some distance, and structures such as helmet streamers can be modeled by postulating that currents are present only in thin sheets. Such methods are sufficient for us to make estimates of the field out of the ecliptic, but it must be emphasized that these are only approximations based on models rather than firm theoretical predictions. There is no substitute for in situ measurements of $\underline{B}$ out of the ecliptic.

II. MAGNETIC FIELD DIRECTION

Parker (1958) presented a model for the zeroth order configuration of the magnetic field lines, assuming constant V_0, B_0, and ρ_0, and steady corotation. In this case, (1) gives the well-known Archemedian spiral. A good illustration of this pattern may be found in Hirose et al. (1970). Measurements have shown that Parker's model given an acceptable zeroth

-145-

order approximation for the field in the ecliptic plane between 0.3 AU and

5 AU (see the review by Behannon, 1975, and the paper by Mariani et al.

(1975)). There is appreciable scatter of the observed points about the

theoretical curve, which might be due in part to variations in $\underset{\sim}{B}_o$ and ρ_o

(Burlaga and Barouch, 1975), and one can expect to observe similar scatter

away from the ecliptic. One might also see systematic effects in the

direction of $\underset{\sim}{B}$ due to systematic variations in $\underset{\sim}{B}_o$ associated with structures

such as helmet streamers and polar plumes.

Stenflo (1971) attempted to compute realistic interplanetary magnetic

field configurations by introducing a reasonable model for $V(r)$ near the

sun, projecting measured photospheric fields to a source surface at $2.6r_\oplus$

using the potential field mapping technique, and mapping fields from the

source surface to 1 AU by a technique equivalent to Eq.(1). An important

result is that although there are complex loop-configurations close to the

sun, farther from the sun the field becomes more radial and only the lowest

harmonics are significant for the solar wind flow. In particular, the

large-scale ($\approx$ 1 AU),3-dimensional field which he computed for the period

Feb. 17 to March 10, 1970 was found to have the spiral form predicted by

Parker's model (see Figure 2).

The pattern that we have been discussing is altered by the presence

of streams. The magnetic field lines will be more radial when the speed

is high than when it is low. This effect is small, however, being just

a few degrees in the ecliptic plane (e.g., see Burlaga and Barouch, 1975)

and probably even smaller at higher latitudes.

III. MAGNETIC FIELD SENSE (SECTORS)

Wilcox and Ness (1965) showed that the interplanetary magnetic field is structured such that it tends to point away from the sun for several consecutive days, then abruptly changes direction by 180° and points toward the sun for several days, etc.. In other words, the "sense" of the field is sectored on the mesoscale. In 1964, four sectors were observed by IMP 1 (Wilcox and Ness, 1967). Several papers, beginning with that of Wilcox and Ness (1965), show that the interplanetary sector structure is related to the polarity of the photospheric magnetic field. In a recent study of this sort, Nolte (1974) (see Roelof, 1974) computed the cross-correlation (calculated over nine solar rotations) between the interplanetary polarities which were mapped to their connection longitudes on the sun using the solar wind speed and an empirical technique and the H_α chromospheric polarities. He found that the cross-correlation peaks at latitudes $+30^o$ and -20°, suggesting that the base of the field lines is generally not in the solar equator; however, the correlation was low, ≈ 0.3. When he computed the cross-correlation coefficient for magnetic field data corresponding to speeds >400km/sec, he found a peak of ~ 0.5 at a latitude very near to the solar equator, suggesting that the streams which are observed originate near the solar equator.

Ness and Wilcox (1967) showed that the sector structure changes with time. Two sectors were observed in 1962, four in 1964, and the structure was complex in 1965. Similar plots for 1970-1972 are given in Fairfield and Ness (1974) together with references to other papers on time variations. Generally, the pattern of 2 or 4 sectors is the dominant one.

Wilcox and Svaalgard (1974) considered an interesting pattern in
1969, when 2 sectors were predominant for several solar rotations.
Comparison with the solar fields, as determined by the "hairy-ball"
(potential field mapping) model, showed that the sector boundary, projected
from 1 AU to the sun, corresponded to an "arcade" of closed loops running
approximately N-S. Thus, one expects that the sector boundary extends
to rather high latitudes in this case.

Altschuler et al. (1974) computed the large-scale photospheric magnetic
field in terms of surface harmonics ($P_n^m (\theta) \cos m\phi$ and $P_n^m (\theta) \sin m\phi$)
for the years 1959 through 1972. For the year 1969 they found that the
dominant pattern was a dipole whose axis was in the solar equatorial
plane; in other words, they found a two-sector pattern, the sector boun-
darys running N-S, consistent with the results of Wilcox and Svaalgard
described above.

Altschuler et al (1974) found that the solar field pattern changed
with time in a way consistent with spacecraft observations of the inter-
planetary magnetic field polarity. For example, in 1962 the dominant
pattern was again a dipole in the equatorial plane, in agreement with the
Mariner 2 observations. In 1963 they found that m=1 and m=2 were equally
frequent, corresponding to 2 sectors and four sectors, respectively,
consistent with the IMP observations. Thus, it appears that the lowest
harmonics of the solar field determine the sector structure and can be
used to predict the sector structure at all latitudes.

Altschuler et al. (1974) found that 2 sectors, with the sense of a

dipole whose axis is in the equatorial plane, is the dominant pattern. They also found that four sectors occur frequently and that a N-S dipole predominates only occasionally. Thus, one expects that generally there will be two sectors whose boundaries extend N-S, sometimes four sectors will be present, and occasionally the polar regions will tend to be unipolar with a "sector boundary" in the solar equatorial plane. The time variations can be very important for a S/C mission lasting more than a year. It will be important to correlate measurements of the solar field, out-of-ecliptic measurements, and measurements made near the ecliptic, to separate the space-time variations

Svalgaard et al. (1974) proposed a model to describe the more complex configurations in which both a N-S dipole and a dipole whose axis is in the equatorial plane contribute to the interplanetary magnetic field. This is illustrated in Figure 3 (bottom), which shows that the polar fields and the equatorial fields might combine to give sector boundaries that are tilted with respect to the solar equator, the direction of tilt depending on the polarity of the fields. The figure also illustrates the magnetic arcades and the associated helmet streamers that are presumed to be associated with sector boundaries. Svalgaard et al. (1974) presented evidence that strongly supports this picture for the period that they studies. An alternative model (see Figure 3) was presented by Hansen et al. (1972) based on data obtained in 1972, when 4 sectors were observed at 1 AU and coronal streamers were observed by OSO-1. Hansen et al. postulate a coronal bridge corresponding to the low-latitude arcades of Svalgaard et al., but they differ in postulating independent

streamers at high latitudes. The relative merits of these two models has not been established. Out-of-ecliptic measurements could be decisive.

Rosenberg and Coleman (1969) showed that the number of days with negative polarity varied sinusoidally with a period of 1 year between 1964 and 1967, randomly in 1968-1969, and sinusoidally with a 180° phase shift in 1970-1973. This pattern showed the expected change in 1974-1975 (Fairfield and Ness, 1974). Following a suggestion of Rosenberg and Coleman (1969), Schulz (1973) suggested that this is a consequence of "warping" of the equatorial plane (minimum B surface) of a dominantly N-S solar dipole with significant quadrupole contributions. This conflicts with the results of Altschuler et al. (1974) which show that the N-S dipole is not frequently observed at the sun. It also implies that the sector boundaries should trace a "sinusoidal" line with small amplitude about the solar equator, in contradiction with the results of Svalgaard et al. which suggested that sector boundaries are not tilted so much. This difference has not been resolved, but could be settled by an out-of-ecliptic mission.

IV. MAGNETIC FIELD INTENSITY

Parker's model, based on the assumption of constant and uniform V and B_0, provides the zeroth order approximation of the interplanetary magnetic field intensity. It predicts the measured value of $\approx 5\gamma$ in the ecliptic plane at 1 AU for reasonable values of B_0 near the sun, and it predicts somewhat smaller fields near the poles. A somewhat more complicated model, assuming constant V and a N-S dipole giving $\underset{\sim}{B}_0$, was discussed by Parker (1958) and considered in more detail by Stern (1964).

In view of the results of Altschuler et al. (1974), which showed that a N-S dipole rarely dominates, this model is generally not appropriate.

Superimposed on the large-scale variations in magnetic field intensity are non-uniformities due to streams. These are the result of $\nabla_o X \neq 0$ in Eq. (1). Faster plasma overtakes slower plasma, causing a compression of the plasma and (because the field is "frozen" to the plasma) an enhancement in B. Shears in V can also cause a change in the magnetic field intensity, and this too is implicit in (1) (see Burlaga and Barouch, 1975). Enhancements in B are generally observed at the leading edge of streams at 1 AU, often as large as four times the ambient value. Similar enhancements might be observed out of the ecliptic, depending on the velocity profiles. They might be the most important magnetic field intensity variations at high latitudes. Illustrative spatial configurations of the magnetic field intensity on a spherical shell with radius 1 AU, relative to the unperturbed equatorial field at 1 AU, are shown in Figure 4 from Barouch and Burlaga (1975a). At the top, is the result for $V = V_o$ $(1+A \cos 4\phi)$ $\cos \theta$; at the bottom is the result for $V = V_o$ $(1+A \cos 4\phi) \exp[-(\theta - \theta_o)/\theta_w]^{-2}$. In the first case, one expects that the field intensity might be approximately twice the unperturbed intensity in some regions out of the ecliptic, if the streams extend to high latitudes. In the second case, in which streams are confined near the ecliptic, B(θ) is strongly perturbed only near the ecliptic.

Billings and Roberts (1955) suggested that streams come from regions of open and diverging magnetic field lines near the sun and that slow plasma is associated with closed loops. This is consistent with the

observation that the solar wind speed is generally small near sector boundaries, which according to Svalgaard et al. (1974) are associated with "arcades" of closed loops near the sun. It is also consistent with mappings of streams back toward the sun (Roelof, 1974). Pneuman (1973) and Pneuman and Kopp (1970, 1971) modeled this situation with a dipole in the solar equatorial plane. The basic idea is that when the field lines diverge, heat is readily conducted to the critical point where it can effectively accelerate the solar wind, whereas when the field lines are closed heat cannot be conducted radially because of the low perpendicular conductivity and energy is not available for acceleration. Of course, other models are also possible. The point that we wish to emphasize is that stream profiles might be related to the magne field near the sun. Calculations which explore the consequences of variable $B_o(\theta,\phi)$ are given in Barouch and Burlaga (1975a). The result is that there might be a latitudinal variation of the stream induced perturbations in B which results from the latitudinal dependence of B_o.

We conclude that streams induce significant distortions in the magnetic field intensity which must be considered in measuring a "zeroth" order field. They are also interesting in themselves and may help to understand the source of streams. Finally, they have important effects on solar particles, galactic particles, and possibly solar wind flow perturbations, as discussed in the next section.

V. EFFECTS OF $B(\theta,\phi)$ ON COSMIC RAYS AND PLASMA

Several authors (e.g. see the review of Montgomery, 1975) suggested that particles should have easier access and shorter paths if they enter

the solar system over the radially diverging polar field, then if they enter the tightly wound spiral in the ecliptic. The actual effect is not known, since it depends on the fluctuations of B away from the ecliptic as well as on the large scale topology. Direct measurements would be decisive.

It has also been suggested that mesoscale configurations associated with shock waves (Gold, 1959; Parker, 1963) can appreciably perturb cosmic rays and cause "Forbush decreases" in their intensity, and there is some evidence in support of this view (e.g. Barnden, 1973). Obviously, latitudinal variations in such configurations would have corresponding effects on the cosmic rays, but direct measurements are needed to determine the nature of these variations and the size of the effects.

The presence of stream-induced gradients in B can also significantly affect cosmic rays. Barouch and Burlaga (1975b) showed that Forbush decreases and similar galactic cosmic ray intensity variations are strongly correlated with magnetic field enhancements associated with streams. They proposed that these are the results of perpendicular gradient drifts, and Barouch and Burlaga (1975a) showed that the drift speeds are appreciably higher than the speeds in streams, as required. If streams extend to high latitudes, one expects to observe Forbush decreases there. If streams do not extend to high latitudes, there will be small drifts due to the spiral field configuration (Winge and Coleman, 1968), but there may be no observable effects.

Streams cause field lines to diverge less rapidly and eventually converge in the compression regions in front of streams. Thus, solar particles moving in such mesoscale configurations will be collimated less

strongly than in the large-scale spiral field, and some will mirror
(Barouch and Burlaga 1975a), giving stream related intensity and anisotropy
profiles. One expects systematic differences in these profiles with in-
creasing latitude, depending on the variations of the streams.

Low energy (thermal) particles are also influenced by the magnetic
field, although not as strongly as the high energy particles whose energy
density is much less than $B^2/(8\pi)$. In fact, Parker's model, which assumes
constant V and gives a spiral field, is not exactly self-consistent for
this reason (Gussenhoven and Carovillano, 1973; Alekseyer et al. 1971).
In particular, the spiral field gives a $\underline{J}x\underline{B} = (\nabla x\underline{B})x\underline{B}$ force that causes
a meridional flow away from the ecliptic. This flow has been studied by
Winge and Coleman (1974) and by Suess (1974). Its magnitude might be as
much as ≈ 1 km/sec in the ecliptic at 1 AU. Rosenberg and Coleman (1973)
invoked this flow and the frozen field condition to explain his observations
that the magnetic field direction diverges away from the ecliptic plane.
These effects are small and have not been confirmed. They vary with
latitude in the spiral field configuration, and they might be strongly
modified by streams.

VI. SUMMARY

One expects the large-scale, three-dimensional magnetic field lines
of the solar wind to have the form of spirals wrapped on cones, as
described by the solutions of Parker. Solar wind streams and solar
magnetic field configurations probably will not alter this very much,
although small, systematic effects due to the variation of the orientation
of $\underline{B}$ near the sun might be observable.

The sector pattern possibly extends to high latitudes and can change appreciably during a year. The pattern and extent of sector boundaries is a matter of controversy. Extrapolations of the solar field and mapping of the interplanetary field to the sun suggest that the boundaries extend nearly north-south, although tilted somewhat depending on the polar and sector field directions. On the other hand, the "Rosenberg-Coleman dominant polarity effect" and some calculations suggest that sector boundary surfaces are confined closer to the equator. Two distinctly different models of sector boundaries have been proposed by Svalgaard et al. and Hansen et al., but one cannot chose one or the other at the moment.

The interplanetary magnetic field intensity will vary with latitude depending on the photospheric field configuration. For a solar monopole, the polar field near 1 AU is $\approx \sqrt{2}$ smaller than the equatorial field. The intensity might vary more than this on a smaller scale, ≤ 1 AU, due to the presence of streams. The actual configuration depends on both the stream profiles and the magnetic field intensity profiles near the sun, but these are not known at present.

The gradients in magnetic field intensity produced by streams cause energetic particles to drift away from the ecliptic, and they might be responsible for Forbush decreases. If so, these decreases should disappear at high latitudes if the speeds are confined near to the ecliptic. Stream induced magnetic field enhancements might also mirror solar particles and reduce their collimation, causing stream-related changes in intensity and anisotropy. The effect varies with latitude in a systematic way, so that one can test these ideas with an out-of-the-ecliptic mission.

The large-scale spiral field causes a small meridional flow as a consequence of the $J \times B$ force. The magnitude of this flow might be altered by streams and vary with latitude for this reason.

In conclusion, an out-of-the-ecliptic mission will allow us to test present models of the interplanetary magnetic field, resolve some controversies, provide information needed to understand energetic particle and plasma motions, and it will probably give new results that we cannot anticipate.

References

Aleksecev, I.I., V.P. Shebansky, and A.R. Shister, Spherically symmetric outflow of plasma from the sun, Geomag. and Aeron., 11, 651, 1971.

Altschuler, M.D., D.E. Trotter, G. Newkirk, Jr., and R. Howard, The Large-scale solar magnetic field, Solar Physics, 39, 3, 1974.

Barnden, L.R., The large-scale magnetic field configuration associated with Forbush decreases, Proc. Int. Conf. Cosmic Rays 13th, 2, 1277.

Barouch, E., and L.F. Burlaga, Three-dimensional interplanetary stream magnetism and energetic particle motion, submitted to J. Geophys. Res., 1975a.

Barouch, E., and L.F. Burlaga, Causes of Forbush decreases and other cosmic ray variations, J. Geophys. Res., 80, 449, 1975b.

Behannon, K.W., Variation of the interplanetary magnetic field with heliocentric distance, NASA/GSFC X-692-75-143, 1975.

Billings, D.E., and W.O. Roberts, Solar corpuscles responsible for geomagnetic disturbances, J. Geophys. Res., 60, 33, 1955.

Burlaga, L.F., and E. Barouch, Interplanetary stream magnetism: kinematic effects, Astrophys. J., in press, 1975.

Fairfield, D.H., and N.F. Ness, Interplanetary sector structure: 1970-1972, J. Geophys. Res., 79, 5089, 1974.

Gold, T., Plasma and magnetic fields in the solar system, J. Geophys. Res., 64, 1665, 1959.

Gussenhoven, M.S., and R.L. Carovillano, Restrictions on radial magnetic field and flow solutions for the solar wind, Solar Physics, 29, 233, 1973.
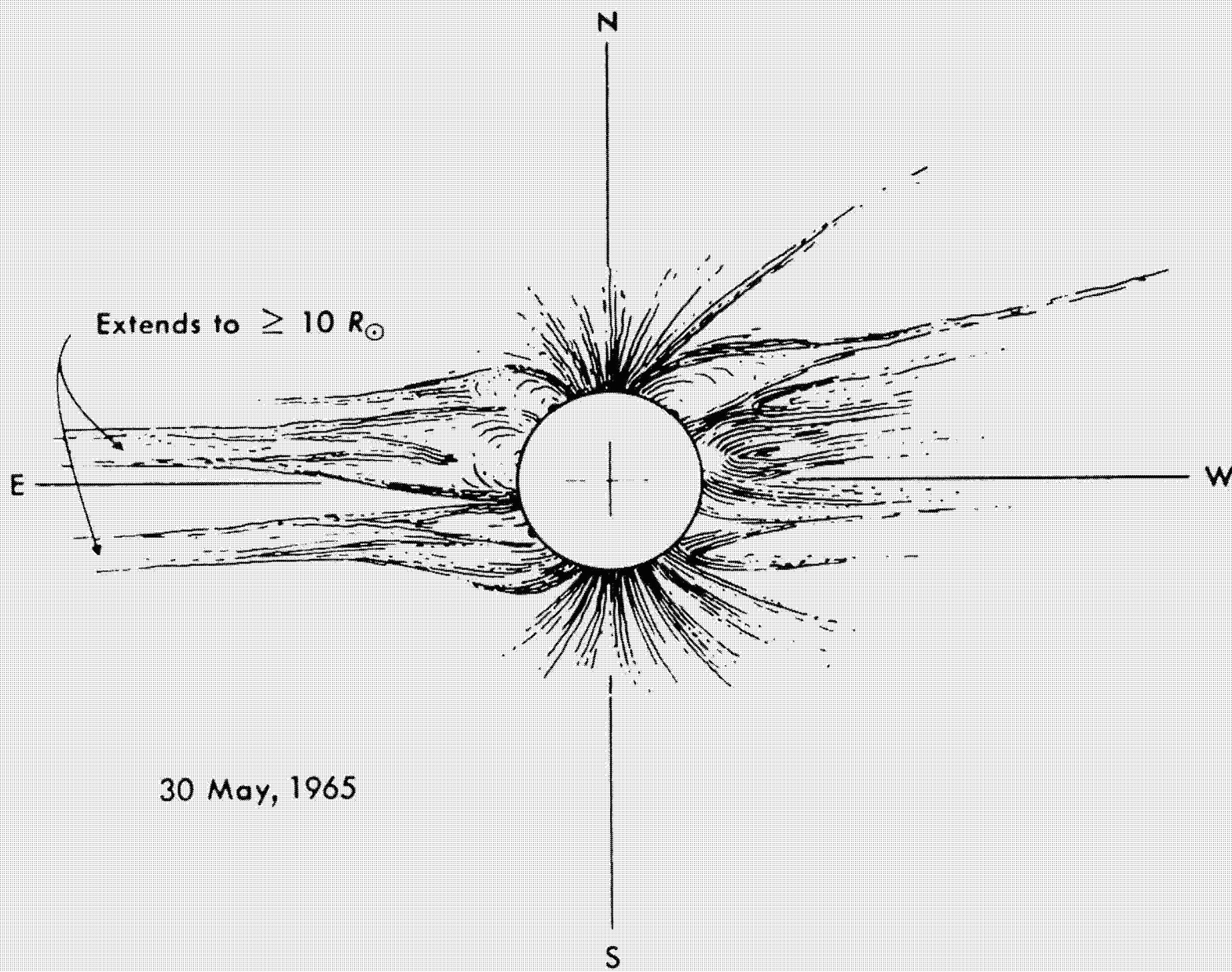
Hansen, S., R.T. Hansen, and C.J. Garcia, Evolution of coronal helmets during the ascending phase of solar cycle 20, Solar Physics, 26, 202, 1972.

Hirose, T., M. Fujimoto and K. Kawabata, Magnetohydrodynamical processes of the sector structure of the solar wind, Pub. Astron. Soc. Japan, 22, 435, 1970.

Mariani, F., N.F. Ness, L.F. Burlaga, S. Cantarano, B. Bavassano and U. Villante, Radial and time variations of the interplanetary magnetic field between 1 AU and 0.3 AU, Technical Report - LPS-75-1975.

Nolte, J.T., Inter-relationship of energetic particles, plasma and magnetic fields in the inner heliosphere, Ph.D. Dissertation, University of New Hampshire, 1974.

Nolte, J.T., and E.C. Roelof, Large-scale structure of the interplanetary medium, Solar Phys., 33, 483, 1973.

Parker, E.N., Dynamics of the interplanetary gas and magnetic fields, Astrophys. J., 128, 664, 1958.

Parker, E.N., Interplanetary Dynamical Processes, p. 177, Interscience, New York, 1963.

Pneuman, G.W., The solar wind and the temperature-density structure of the solar corona, Solar Physics, 28, 247, 1973.

Pneuman, G.W., and R.A. Kopp, Coronal streamers: III. Energy transport in streamer and interstreamer regions, Solar Physics, 13, 176, 1970.

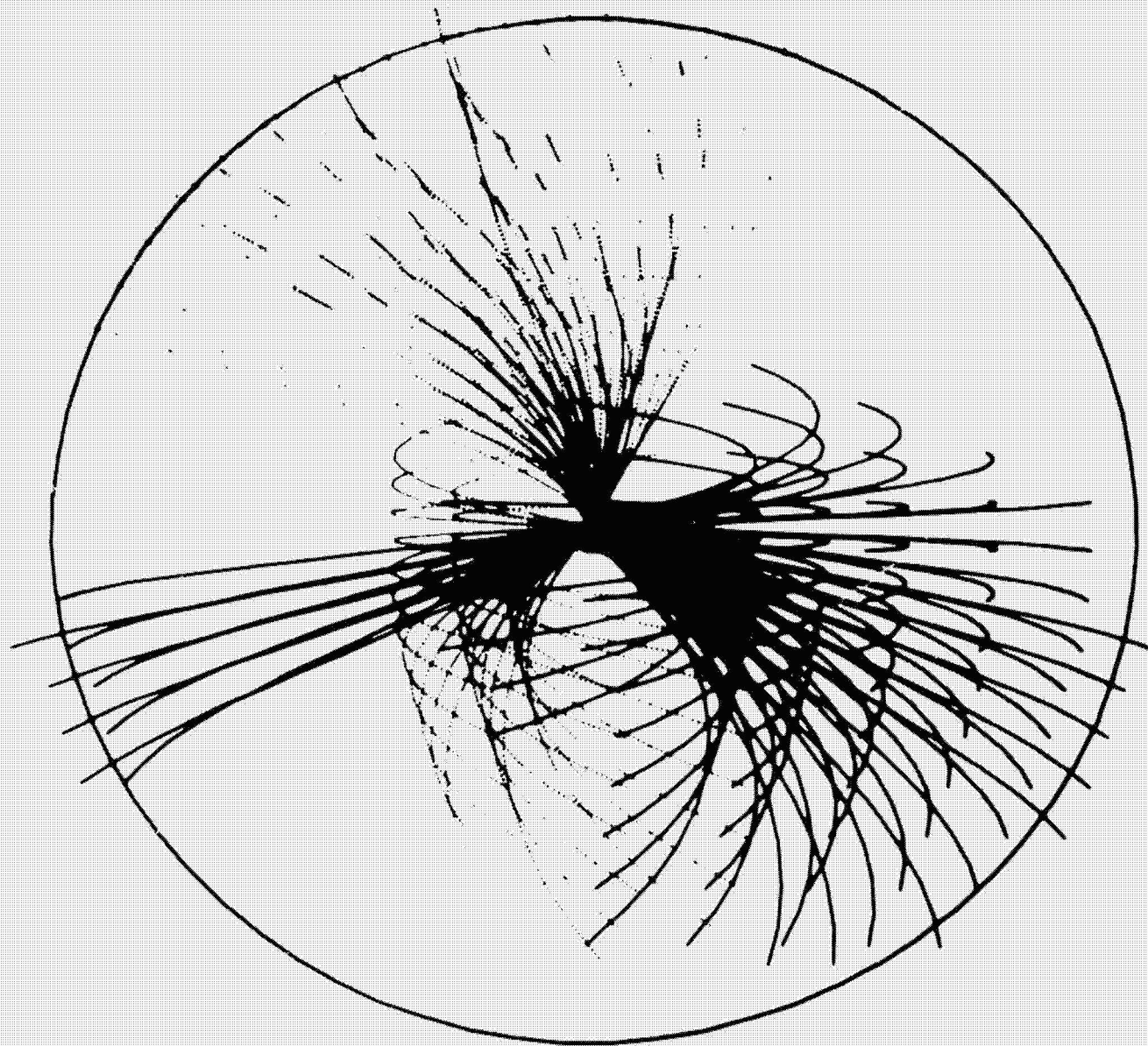Pneuman, G.W., and R.A. Kopp, Gas-magnetic field interactions in the solar corona, Solar Physics, 18, 258, 1971.

Roelof, E.C., Coronal structure and solar wind, in <u>Solar Wind Three</u>,

    p. 98, ed. C.T. Russell, Institute of Geophysics and Planetary

    Physics, University of California, Los Angeles, 1974.

Rosenberg, R.L., and P.J. Coleman, Jr., Latitude dependence of the

    dominant polarity of the interplanetary magnetic field, <u>J. Geophys.</u>

    <u>Res.</u>, 74, 5611, 1969.

Rosenberg, R.L., and P.J. Coleman, Jr., Further study of the θ component

    of the interplanetary magnetic field, <u>J. Geophys. Res.</u>, <u>78</u>, 51, 1973.

Schatten, K.H., Current sheet model for the solar corona, <u>Cosmic</u>

    <u>Electrodynamics</u>, <u>2</u>, 232, 1971.

Schatten, Large-scale properties of the interplanetary magnetic field,

    in <u>Solar Wind</u>, ed. C.P. Sonett, P.J. Coleman, Jr., and J.M. Wilcox,

    p. 65, NASA SP-308, 1972.

Schulz, M., Interplanetary sector structure and the heliomagnetic equator,

    <u>Astrophys. and Space Science</u>, <u>24</u>, 371, 1973.

Stenflo, J.O. The coronal and interplanetary magnetic fields at the time

    of the solar eclipse of 7 March 1970, <u>Solar Physics</u>, <u>21</u>, 263, 1971.

Stern, D., A simple model of the interplanetary magnetic field, <u>Planet.</u>

    <u>Space Sci.</u>, <u>12</u>, 961, 1964.

Suess, S., Three dimensional modeling, in Solar Wind Three, p. 311, ed.

    C.T. Russell, Institute of Geophysics and Planetary Physics,

    University of California, Los Angeles, 1974.

Svalgaard, L., J.M. Wilcox and T.L. Duvall, A model combining the

    polar and sector-structured solar magnetic fields, <u>Solar Physics</u>,

    <u>37</u>, 157, 1974.

Wilcox, J.M. and N.F. Ness, Quasi-stationary corotating structure in
the interplanetary medium, J. Geophys. Res., 70, 5793, 1965.

Wilcox, J.M. and N.F. Ness, Solar source of the interplanetary sector
structure, Solar Phys., 1, 437, 1967.

Wilcox, J.M., and L. Svalgaard, Coronal magnetic structure at a solar
sector boundary, Solar Physics, 34, 461, 1974.

Winge, C.R., and P.J. Coleman, Jr., The motion of charged particles
in a spiral field, J. Geophys. Res., 73, 165, 1968.

Winge, C.R., Jr., and P.J. Coleman, Jr., Theoretical predictions of
latitude dependencies in the solar wind, in Solar Wind Three,
p. 318, ed. C.T. Russell, Institute of Geophysics and Planetary
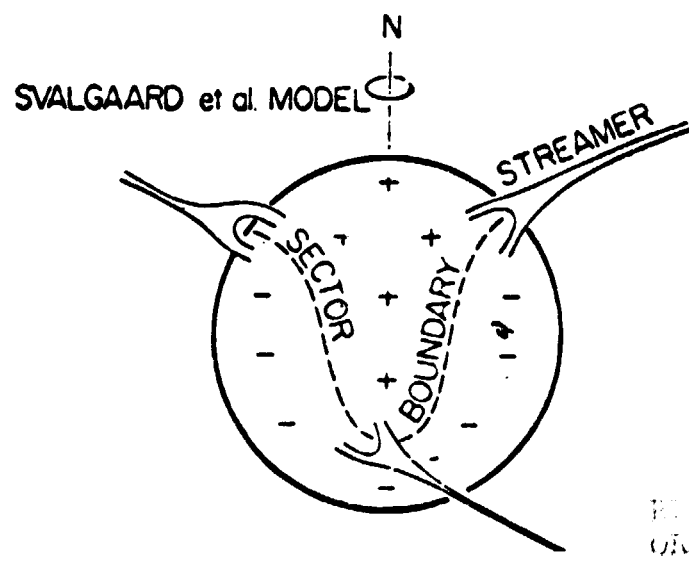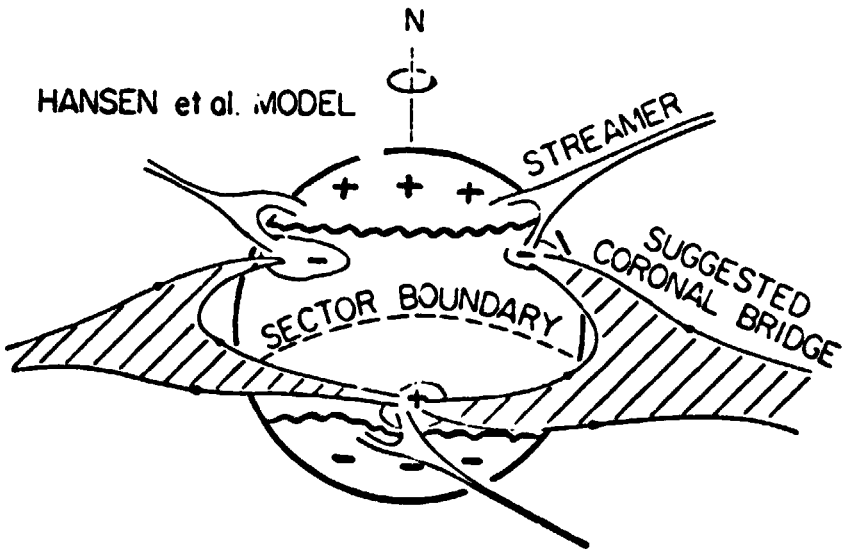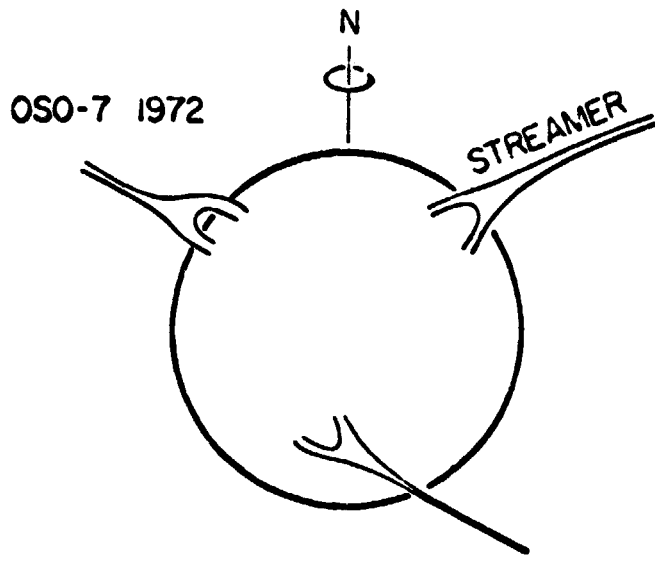Physics, University of California, Los Angeles, 1974.

Figure 1   Sketch of a solar eclipse on 30 May 1965. The contours

are believed to indicate the direction of the magnetic

field

Figure 2   Interplanetary magnetic field lines on a scale of 1 AU,

seen by an observed in the ecliptic plane. They were

computed by Stenflo using photospheric magnetic field

measurements.

Figure 3   Sector boundaries. This illustrates two conceptual models

of sector boundaries and their relation to coronal streamers.

Figure 4   Magnetic field intensity contours relative to the un-

perturbed intensity in the ecliptic plane at 1 AU, on a

surface with radius 1 AU. The top figure shows the

pattern caused by a stream which varies with latitude as

$\cos \theta$, and the bottom figure describes the result of a

stream which is confined near the ecliptic.

N

Extends to $\geq 10\ R_{\odot}$

E

W

S

30 May, 1965

LONGITUDE OF DISK CENTER= 0 DEGREES

OSO-7 1972

HANSEN et al. MODEL

SVALGAARD et al. MODEL